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MAGNETOELECTRIC MECHANISM FOR AUTOMATIC CONTROL

AND GOVERNING DEVICES

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The articles describes a method for designing magnetoelectric mechanisms, intended for continuous control with automatic control and regulation devices, in cases where measurement of the controlled parameter and preliminary amplification is accomplished by electrical methods. Calculated formulas and experimental researches are brought out.

The cycle of automatic control or regulation of any industrial parameter begins with the determination of the value of the parameter and ends with the fulfillment of the operation necessary for recording this magnitude, or the reaction to it. The measurement of many industrial parameters, differing in their physical nature, is carried out by electrical methods, whereas in many cases a hydraulic or pneumatic-performing mechanism is used for accomplishing the final work. For controlling these mechanisms, a mechanical motion of the regulating device is required, for example a slide, a jet tube, or a needle valve, for which a considerable force on the order of 20 to 50 grams is necessary. If the control device has to occupy only extreme positions (for instance two-way regulation), its movement can be achieved by an ordinary relay, fed from the electrical and amplification system. It is, though, frequently necessary that the position of the control device change continuously as a function of the value of the controlled parameter. In such cases, the relay can no longer serve/as an intermediate link between the electric measuring and amplification system on one hand, and as a hydraulic or pneumatic-performing mechanism on the other hand. This problem can be solved strictly through a servo drive mechanism. However, in many cases,

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~~a fully satisfactory solution can be achieved by means of mechanisms
with special traction properties. Such mechanisms can be brought into
operation directly through plate current of an electronic tube, as a result
of which the installation of the automatic control or regulating device
is simplified.~~

The following
~~Given below~~ is a description of the principle of operation, design
methods, and the operating characteristics of the mechanism whose moment
is proportional to the current value. It can be used to solve a series
of problems of automatic regulation and control. In accordance with
the principle of operation and the functional designation this mechanism,
it is called the "Magnetoelectric traction mechanism" (Abbr. MTM).

The outline drawing of the mechanism (the principle of this mechanism
was introduced by Prof. V. A. Trapeznikov) is indicated in Fig. 1. It
contains a permanent cylindrical magnet 1, polarized lengthwise along
one of the diameters of the magnetic circuit 2 and the coil 3, through
which direct current flows. The movable part is the magnet, which
can revolve around its axis. If a direct current is flowing through
the coil, the magnet tries to take such a position that the direction of
its own magnetic flux will coincide with the magnetic flux caused by
the coil; under these conditions, the magnet developes a mechanical
moment. The problem of computation lies in determining the value of the
mechanical moment, developed by the magnet MTM at different values of
current intensity in the coil, providing that the material and the dimensions
of the magnet and of the pole frame, and the number of the coil-turns,
are known.

The first step in the computation is to determine the induction
and the field intensity inside the magnet. The relation between the
field intensity and the induction inside of the material is expressed by
a magnetization curve, characteristic for every material. Curve 1
in Fig. 2 represents a part of the magnetization curve for "al'in" alloy,

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produced by our industry /1/. One can plot, along this curve a magnetic intensity curve J, using the well known relationship

$$ \text{(1)} $$

The magnetization intensity of the considered material is represented in curve 2 of Fig. 2.

The field inside of the magnet is formed by an external source (for example the coil through which flows the current) and the ends of the magnetized body (2) itself. After the process of magnetization is completed, and the external field is eliminated, the magnetic condition of the material will be different, depending on whether the magnetic circuit is closed or open. Thus, if the circuit is closed, this condition will be indicated by point B_r, in Fig. 2, corresponding to $H = 0$. But if the circuit is open, the magnetic poles formed on the ends will produce a demagnetizing field inside of the material, and the settled state will be such, as to satisfy the condition

$$ \text{(2)} $$

In order to determine this steady state, it is necessary to know the intensity of the demagnetizing field formed by the poles, the determination of which can be done by a number of grapho-analytic and empirical methods /3/, /4/.

For infinitely long, cylindrical magnets, polarized along one of the diameters, the relationship between the intensity of magnetization and the intensity of the demagnetizing field, created by the ends /5/ is

$$ \text{(3)} $$

This relationship is indicated in Fig. 2 by the straight line OC; its intersection with curve (2) gives the value of magnetization intensity J_o, which will characterize the condition of the magnetic

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material in the absence of ferromagnetic bodies near it. The induction B_0 corresponds to this magnetization intensity.

When the magnet is inserted in the pole frame, condition (3) is satisfied with other values of B and H, i. e., the magnetic state of the material will be different, and in the process of transition to a new stage, the relationship between B and H is different than in the process of magnetization; its graphic representation is called the return curve; the return curve of "Al'ni" alloy is described in Fig. 2 by the straight line B_0A.

As known/5/, a cylindrical body with diametrical magnetization, in an adequately strong homogenous field, is polarized evenly. Assuming that this method of polarization will also be preserved by placing the magnet into the mounting, and considering that the clearance is small in comparison to the cylinder radius, and the magnetic pole frame is not saturated, so that one can disregard the decrease of its magnetic intensity, the following relation may be obtained between the magnetic induction in the body of the magnet and the intensity of the demagnetizing field, for an arbitrarily chosen force tube (Fig. 3):

$$\text{Insert of P. 5} \tag{4}$$

where Q is the area of the cross section, L - the length of the magnetic tube, the index $_M$ refers to the material of the magnet, and the index sub-B refers to the air.

For the arbitrarily chosen tube (Fig. 3), considering that the axial measurements of the magnet and the air interval are equal,

$$\text{Insert equations page 5-6} \tag{5}$$

according to which the relationship (4) can be brought to the form

$$\text{Insert of P 56} \tag{6}$$

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This relationship, indicated in Fig. 2 by the straight line α', has to be satisfied by the induction and the field intensity in the material of the magnet, tied in, moreover, with the characteristic of the material (return curve). Consequently, the condition of the material, after its introduction into the pole frame, will be identical in the entire volume of the magnet and will be characterized by point F (Fig. 2), i. e. by the induction B_e and the field intensity H_e.

By calculations, according to the described method for end-length magnets, for which the relationship (3) is no longer correct, results are obtained very similar to those obtained by experiment, which gives evidence of the insignificant influence of the distorted field at the ends of the magnet on the magnetic condition of material with great rententivity.

The second stage of calculation is the determination of the value of mechanical moment developed by the magnet under the effect of the coil field.

The measurement of a mechanical moment can be determined from the relationship

$$\text{Inverting Page 5b} \tag{7}$$

Here $d\varphi$ is an elemental deflection angle, dA the mechanical work performed by the drive with a turn of the magnet to an angle $d\varphi$.

There are two sources of energy in the magnetoelectric drive, through which mechanical work can be accomplished:

a) the store of energy in the magnetic field, which can be conditionally divided into energy A_1, connected with the permanent magnet, and energy A_2, connected with the winding.

b) the current source supplying the winding. Specifying the energy put out by the current source during the deflection of the magnet to the angle $d\varphi$ by dA_E, the equation of the energy balance of the

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magnetic field can be written in the form

$$\text{Insert } c_b \quad P \quad 56 \tag{8}$$

Hence from (7) and (8) results

$$\text{Insert } c_j \quad P \quad 56 \tag{9}$$

The magnitude of the field energy of the permanent magnet on a known scale can be represented by the area of the triangle OMA in Fig. 2 /6/. This area changes if the magnetic condition of the material alters, i. e., if point M shifts along the return curve. The magnetic condition of the material of the magnet during its rotation around the axis can be changed by:

    a) variation in the magnetic conductivity for the flux of the magnet,

    b) effect of the external field (coil field).

The first of these causes cannot take place in the considered case, since the polar frame envelopes the magnet evenly over the entire circumference.

One can disregard the effect of the external field on the magnetic condition of the magnet, as a first approximation, at any rate as long as the field intensity, created in the body of the magnet by the current flowing through the winding, is small in comparison with the rententivity of the material. Thus, with sufficient approximation, it can be assumed that

$$\text{Insert equation } 9A', \quad P. 57$$

The energy of the coil field, if we neglect the non-linearity of the magnetic characteristics of materials of the magnetic circuit and the magnet (which is admissible, in practice, since the magnetic circuit works in an induction region far from saturation, and the return

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curve which serves as the working characteristic of the magnet material is very nearly a straight line) can be expressed by the simple formula:

$$ \text{Insert eq. P. 57} \tag{10} $$

where i is the current strength in the coil, L is the inductance of the coil.

$$ \text{Insert eq. P. } \tag{11} $$

w - the number of coil turns, R_m - the combined magnetic resistance to its flow; l_i, Q_i - geometric dimensions, of the elements of the magnetic circuit arranged in series, μ_i - their magnetic permeability. Although the magnetic permeability of the magnet material is not uniform in different directions in regard to the plane of polarization, the rotation of the magnet does not produce any considerable variation of A_2, with the condition that the current in the coil remains unchanged.

Consequently, one can assume

$$ \text{Insert eq. 11A, page 51} $$

If the flux, linked with the coil in which the current i flows, increases by $\Delta \mathcal{F}_{12}$, the amount of energy transmitted from the source of the current to the magnetic field is

$$ \text{Insert eq. P. 57} \tag{12} $$

In our case, the rotation of the magnet by the angle φ from the neutral position (Fig. 4) will cause the flux, emerging from the magnet inside the angle $\pm \varphi$, to close in along the magnetic circuit of the coil. The magnitude of this flux can be found easily. Reading off the flow angle coordinate α from the central plane of polarization of the magnet, we shall find that the flux

$$ \text{Insert eq. P. 58} \tag{13} $$

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discharges from the elementary area on the surface of the magnet; where h is the axial length of the magnet.

The flux which now will go through the coil is

$$\text{Insert eq P 58} \qquad (14)$$

Consequently, the quantity of energy given by the source of the current is

$$\text{Insert eq P 58} \qquad (15)$$

and the turning moment, according to (9), is

$$\text{Insert eq. P 58} \qquad (16)$$

Changing from absolute electromagnetic units to the commonly used ones, and considering that the flux of the magnet is

$$\text{Insert eq P 58} \qquad (17)$$

we obtain a final calculated formula for the turning moment:

$$\text{Insert eq. P 58} \qquad (18)$$

Below are given basic data and the working characteristics of one of the samples of MTM:

Diameter of magnet . . . . $2r = 1.6$ cm

Length of magnet . . . . $h_M = 3$ cm

Length of the air gap . . . . $l_B = 0.05$ cm

Induction in the material of the magnet . . . . $B_M = 1620$ G

Full magnetic flux of the magnet . . . . $\Phi = 7\ 800$ M

Resistance of coil . . . . $R_K = 4\ 200$

Number of turns of coil . . . . $w = 17\ 000$

Substituting in formula (18) the corresponding magnitudes, we shall obtain the following expression for the mechanical moment:

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$$M = 1.02 \times 10^{-4} \, iw \cos \theta = 13.5 \, i \; [g \times cm],$$

where i is the current strength in the coil (mA).

Fig. 5 represents theoretical and experimental curves of the dependence of the moment on the angle of rotation of the rotor.

If the working stroke of the magnet comprises $\pm 10^{\circ}$ to 15° one can consider with sufficient accuracy that the mechanical moment is proportional to the current strength in the coil, as represented in Fig. 6, where is shown the dependence of the moment on the current strength in the coil at different angular positions of the rotor.

Even with a current of 5 mA, which can be obtained from a small amplifying tube, the magnet develops a moment of about 65 g x cm, entirely sufficient, for example, to operate by means of a needle valve a working mechanism of the type "Arka". The small dimensions of the mechanism and the absence of contacts makes this an extremely convenient mechanism for a series of industrial apparatus.

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Fig. 1 Outline of the magnetoelectric traction mechanism   *Page 57 of my doc*

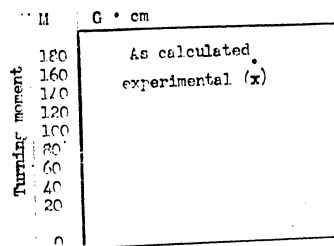Fig. 2 Parts of the magnetization curves of "Al'ni" alloy   *Page 54*

Fig. 3 Magnet calculation of the magnetoelectric traction mechanism   *Page 55*

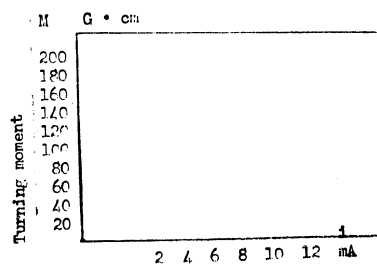Fig. 4 Computation of the value of the driving moment   *P. 55*

Fig. 5 Dependence of the turning moment on the angle of turn of the

magnet.   *P. 58*

M   G • cm

As calculated
experimental (x)

180
160
140
120
100
80
60
40
20
0

Turning moment

Fig. 6 Dependence of the turning moment on the current in the coil

M   G • cm   *P. 59*

200
180
160
140
120
100
80
60
40
20

Turning moment

2 4 6 8 10 12 mA

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